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(12) **EUROPEAN PATENT APPLICATION**

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DE FR GB IT

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(54) **Optical coupling systems with bend**

(57) Disclosed are optical couplers (10) and optical coupling systems for coupling a source of non-coherent light to a light distribution harness, wherein the couplers are polygonal in cross section to increase light mixing. The couplers have inlet (12) and outlet (14) arms and an intermediate bend region (16A) configured to achieve compactness and minimal light loss through the bend region. In one embodiment, the bend region is an integral part of the coupler, with the inlet arm having a different cross-sectional dimension (12A) from the outlet arm (14A) in such manner that substantially all light (30) directed from the inlet portion (12) to the bend portion (16A) reaches (31,32) the outlet arm portion (14), and light rays parallel to the inlet axis are reflected in the bend portion to be directed substantially parallel to the outlet axis. In a second embodiment, the bend region comprises a prism having a pair of parallel spaced surfaces, and inlet, outlet, and third surfaces that are non-parallel to the spaced surfaces. The inlet arm projects from the inlet surface, and the outlet arm projects from the outlet surface. One of the inlet and outlet surfaces forms a first interface with a first material having an index of refraction different from that of the prism, so that light rays within the prism totally internally reflect from the first interface.

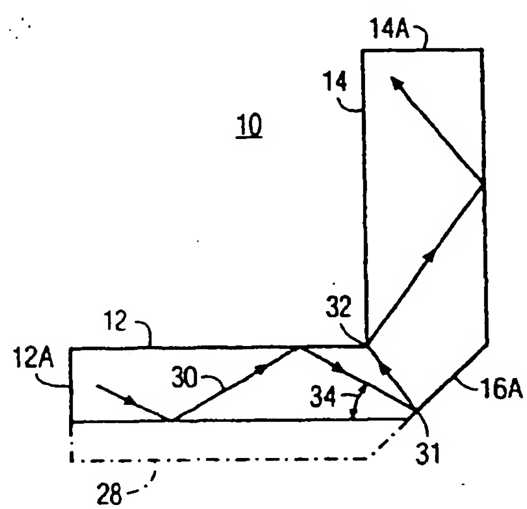

FIG. 2

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Description

The present invention relates to optical couplers and optical coupling systems for coupling a source of non-coherent light to a light distribution harness, wherein the couplers are polygonal in cross section to increase light mixing and incorporate a bend to achieve compactness. More particularly, the present invention relates to the foregoing optical couplers and optical coupling systems wherein light is transmitted through the bend with minimal light loss.

Optical coupling systems employing polygonal optical couplers are known, for instance, from U.S. Patent 5,341,445 issued to J. Davenport and R. Hansler (also present inventors), and assigned to the present assignee. The '445 patent teaches the use of optical couplers for receiving light from a high brightness light source, and outputting the light into distribution harnesses for routing the light to remote optics. In particular, the '445 patent teaches the use of optical couplers whose cross sections are polygonal, e.g., square, rectangular, triangular, or hexagonal. Light from a non-coherent light source that passes into an inlet end of a polygonally shaped coupler becomes mixed to a high degree before passing through an outlet end into a light distribution harness for distribution to output optics (i.e., remote optical fixtures). The highly mixed light exhibits a high degree of uniformity in intensity and color, which is required in many lighting applications.

Using the polygonal couplers of the '445 patent, a desirable degree of light mixing can be achieved if the length of a coupler is sufficiently long. For instance, this may occur in a square, hollow, coupler having a length-to-cross section ratio of 7:1 where the coupler is used in a photographic slide projector or video projector. If the coupler were straight, the overall length of the slide or video projector would be correspondingly long.

One approach to minimizing the length of a coupler is to incorporate a (e.g. 90-degree) bend in the coupler. An initial approach to incorporating a bend in a coupler that is, for instance, square is to form a bend with a bend portion and inlet and outlet arms that are both square. The present inventors have discovered, however, that light transmission through such a coupler is less efficient than can be realized, due to light loss in the bend portion of the coupler.

It is therefore an object of the invention to provide rectangular optical couplers incorporating a bend and optical coupling systems using such couplers that more efficiently couple light from a source of light to a light distribution harness than the foregoing approach.

A first embodiment of the invention provides, in preferred form a coupling member for use in coupling non-coherent light from a source of light to a light distribution harness. The coupling member incorporates a bend, and includes a light transmissive body having an inlet arm for receiving light from the light source, and an outlet arm for providing light to a leading end of a light distribution harness. The light transmissive body further includes a bend portion from which the inlet and outlet arm portions project. The inlet and outlet arm portions have respective central longitudinal inlet and outlet axes which intersect in the bend portion to define a bend plane. The inlet arm portion has a cross section, with respect to the inlet axis, that is rectangular. A pair of inlet sides of the inlet arm portion are parallel to the bend plane. The outlet arm portion has a cross section, with respect to the outlet axis, that is rectangular. A pair of outlet sides of the outlet arm portion are parallel to the bend plane. The cross-sectional width of the pair of inlet sides at a position adjacent the bend portion is dimensioned smaller than the cross-sectional width of the pair of outlet sides at a position adjacent the bend portion in such manner that substantially all light directed from the inlet portion to the bend portion reaches the outlet arm portion, and light rays parallel to the inlet axis are reflected in the bend portion to be directed substantially parallel to the outlet axis. The foregoing coupling member may be incorporated into an optical coupling system including the mentioned source of non-coherent light.

A second embodiment of the invention provides, in preferred form, a coupler arrangement for use in coupling non-coherent light from a source of light to a light distribution harness. This coupler arrangement incorporates a bend, and includes a light transmissive body having an inlet arm for receiving light from the light source, and an outlet arm for providing light to a leading end of a light distribution harness. The inlet and outlet arms each have a respective rectangular cross section along an associated central longitudinal axis of the arm. A bend portion is included and comprises a prism having a pair of parallel spaced surfaces, and inlet, outlet, and third surfaces that are non-parallel to the spaced surfaces. The inlet arm projects from the inlet surface, and the outlet arm projects from the outlet surface. One of the inlet and outlet surfaces forms a first interface with a first material having an index of refraction different from that of the prism, so that light rays within the prism totally internally reflect from the first interface.

The foregoing, and further, objects and advantages of the invention will become apparent from the following description when read in conjunction with the drawing, in which like reference characters designate like or corresponding parts throughout the several views, and in which:

Fig. 1 is a top plan view of a prior art optical coupling member incorporating a bend to achieve compactness.

Figs. 1A and 1B respectively show side views of inlet region 12A and outlet region 14A of Fig. 1.

Fig. 2 is similar to Fig. 1, showing an optical coupling member according to the invention.

Figs. 2A and 2B show side views of inlet region 12A and outlet region 14A of Fig. 2.

Fig. 3 is a detail view of a bend portion of the coupler of Fig. 2.

Fig. 4 is similar to Fig. 2, showing an optical coupling

version of light. In such conversion, considering a single input or output arm, the angle is with respect to the longitudinal axis of the arm, and the area refers to the respective cross sectional areas of light at the inlet and outlet portions of the arm. Where an especially large angle-to-area conversion is desired, the tapers may each define a compound parabolic reflector made in accordance with non-imaging optics, a technology known *per se* in the art.

Referring again to Fig. 2, a phantom line 28 shows the portion of inlet arm 12 that is absent in relation to inlet arm 12 of Fig. 1. The extent of the absent portion, i.e., the reduction to dimension D1 for inlet arm as shown in Fig. 2A, is determined by the goal of transmitting all light rays through coupler 10, from inlet region 12A to outlet region 12A. Thus, light ray 30, which reaches 45-degree, mirrored surface 16A at point 31, reflects at point 32 within outlet arm 14, to pass upwardly and be transmitted though outlet region 14A. With light ray 30 representing light deviating from the longitudinal axis (not shown) of inlet arm 12 at a maximum angle 34, determining the reduced dimension D1 (Fig. 2A), compared to dimension D3 of outlet arm 14 (Fig. 2B), is a matter of geometry. For the example shown, with a 90-degree bend in the coupler, D1 = D3 (1 + tangent of angle 34).

Fig. 3 is a detail view of bend portion 16 of a coupler 10, and of adjacent portions of inlet and outlet arms 12 and 14 of the coupler. A so-called backup, or separate, mirror 40 is shown mounted on angled surface 16A of the bend, and is preferably used rather than a mirrored surface 16A as described with the above embodiments where coupler 16 is a solid, rather than hollow, in construction. This is because a thin air layer that will exist between surface 16A and the mirror will cause much of the light reaching angled surface 16A to totally internally reflect within bend portion 16. As opposed to such lossless change of direction, about one-third of the light reaching surface 16A will be angled such that it passes outside of surface 16A to be reflected by the backup mirror, resulting in only one-third of the light having a mirror-absorbed light loss on the order of ten percent.

Fig. 4 shows a coupler 10 whose inlet region 12A is square, as shown in Fig. 4A, and whose outlet region 14A is rectangular, as shown in Fig. 4B. For use in projecting video images from a photographic slide or liquid-crystal display (not shown), the aspect ratio of output dimension D3 to D4 (Fig. 4B) is typically 1.3:1. Determining the dimension D1 of inlet arm 12 (Fig. 4A), compared to dimension D3 of outlet arm 14 (Fig. 4B), can be accomplished in the same manner as determining the corresponding dimensions with respect to the embodiment of Figs. 2, 2A and 2B, as described above.

Figs. 5A and 5B respectively show top and side plan views of an optical coupling system using the coupler of Figs. 4, 4A and 4B. Within an enclosure 42, coupler 10 is arranged to receive light in inlet arm 12 from a source of light 44, via a mirror 46 shown in Fig. 5B. After passing through coupler 10 to achieve a high degree of light mixing, light passes though an image-containing plate 46 before being directed, via a projection lens 48, to display optics (e.g., a viewing screen). In a limiting case, the image-containing plate is perfectly transparent, and the system is used for projecting a uniform area of light.

Fig. 6 shows an optical coupler 10 including a bend portion 16 with a 120-degree bend, or angle 50. As a general rule, bend surface 16A is oriented at an angle 52 of half angle 50, or 60 degrees for the case shown. Determining the relation between dimension D1, of inlet arm 12, and D3, of outlet arm 14, is done in the same manner as mentioned above with respect to Fig. 2, 2A and 2B. For the 120-degree angle 50 shown, dimension D3 is approximately four times dimension D1; for larger angles 50, dimension D3 will be scaled even more upwardly with respect to dimension D1.

Fig. 7 shows a limiting case where dimension D3 of outlet arm 14 is the same as dimension D1 on inlet arm 12, and light rays directed into inlet arm 12 are all passed into outlet arm 14. In this limiting case, the angle 50 of bend is 60 degrees. For angles in excess of 60 degrees, dimension D3 will exceed dimension D1 as in the previous examples of the invention.

A further approach to forming a bend in an optical coupler is now described in connection with Fig. 8 and succeeding figures. Fig. 8 shows a prior art coupler 60 having input and output arms 62 and 64, and a bend region 66 with a mirrored surface 66A. As shown in Figs. 8A and 8B, inlet arms 62 and 64 may have respective, square, equal-size ends 62A and 64A (not shown in Fig. 8). If coupler 60 is hollow, phantom lines 63 and 65 in Figs. 8A and 8B, respectively, represent interiorly reflecting surfaces; if, alternatively, coupler 60 is solid, surfaces 63 and 65 are not present.

As shown in Fig. 8, a light ray 70 reflects from point 71 on mirrored surface 66A back into inlet arm 62, representing lost light. Similarly, light ray 72 passes straight through bend region 62 and exits output arm 64 at point 73; this is because the angle 74 it makes with respect to a central, longitudinal axis of outlet arm 64 is too high to allow the ray to totally internally reflect at point 73 back within outlet arm 64.

Fig. 9 shows an inventive coupler 60 which avoids the lost light of the coupler of prior art Fig. 8 described above. In Fig. 9, bend portion 66 comprises a prism with all surfaces polished, whose surface 66A may be mirrored if desired, as discussed below. Bend portion (or prism) 66 has an upwardly facing surface 66B, for receiving light from inlet arm 62, and a rightward facing surface 66C, through which light is passed into outlet arm 64. As shown in Figs. 9A and 9B, inlet arms 62 and 64 may have respective, rectangular equal-size ends 62A and 64A (not shown in Fig. 9), although the ends may be square. If coupler 60 is hollow, phantom lines 63 and 65 in Figs. 9A and 9B, respectively, represent interiorly reflecting surfaces; if, alternatively, coupler 60 is solid, surfaces 63 and 65 are not present.

Claims

1. A coupling member for use in coupling non-coherent light from a source of light to a light distribution harness, said coupling member incorporating a bend and comprising:

   (a) a light transmissive body including an inlet arm for receiving light from the light source, and an outlet arm for providing light to a leading end of a light distribution harness; said light transmissive body further including a bend portion from which said inlet and outlet arm portions project;
   (b) said inlet and outlet arm portions having respective central longitudinal inlet and outlet axes which intersect in said bend portion to define a bend plane;
   (c) said inlet arm portion having a cross section, with respect to said inlet axis, that is rectangular; a pair of inlet sides of said inlet arm portion being parallel to said bend plane;
   (d) said outlet arm portion having a cross section, with respect to said outlet axis, that is rectangular; a pair of outlet sides of said outlet arm portion being parallel to said bend plane; and
   (e) the cross-sectional width of said pair of inlet sides at a position adjacent said bend portion being dimensioned smaller than the cross-sectional width of said pair of outlet sides at a position adjacent said bend portion in such manner that substantially all light directed from said inlet portion to said bend portion reaches said outlet arm portion, and light rays parallel to said inlet axis are reflected in said bend portion to be directed substantially parallel to said outlet axis.

2. The coupling member of claim 1, wherein said bend portion is configured to achieve a non-perpendicular bend or a perpendicular bend between said inlet and outlet axes.

3. The coupling member of claim 2, wherein said cross-sectional width of said pair of sides of said outlet arm portion is substantially equal to the mathematical product of said cross-sectional width of said pair of sides of said inlet arm portion and the sum of the value of one as augmented by the tangent of the maximum angle of light transmitted in said outlet arm portion with respect to said outlet longitudinal axis.

4. The coupling member of claim 1, wherein at least one of said inlet and outlet arms is tapered along its central longitudinal axis.

5. An optical coupling system for coupling non-coherent light from a source of non-coherent light to a light distribution harness, comprising:

   (a) a source of non-coherent light;
   (b) a coupling member according to any one of claims 1 to 5; and
   (c) a distribution harness comprising an image-containing plate positioned adjacent an output end of said outlet arm; and a projection lens spaced from said image-containing plate for projecting an image on said plate to another location.

6. A coupler arrangement for use in coupling non-coherent light from a source of light to a light distribution harness, said coupler arrangement incorporating a bend and comprising:

   (a) a light transmissive body including an inlet arm for receiving light from the light source, and an outlet arm for providing light to a leading end of a light distribution harness; said inlet and outlet arms each having a respective rectangular cross section along an associated central longitudinal axis of said arm;
   (b) a bend portion comprising a prism having a pair of parallel spaced surfaces, and inlet, outlet, and third surfaces that are nonparallel to said spaced surfaces; said inlet arm projecting from said inlet surface, and said outlet arm projecting from said outlet surface; and
   (c) one of said inlet and outlet surfaces forming a first interface with a first material having an index of refraction different from that of said prism, so that light rays within said prism totally internally reflect from said first interface.

7. The coupler arrangement of claim 6, wherein the other of said inlet and outlet surfaces forms a second interface with a second material having an index of refraction different from that of said prism, so that light rays within said prism totally internally reflect from said second interface.

8. The coupler arrangement of claim 6, wherein said bend portion is configured to achieve a non-perpendicular bend or a perpendicular bend between said inlet and outlet arms.

9. The coupler arrangement of claim 6, wherein at least one of said inlet and outlet arms is tapered along its central longitudinal axis.

10. The coupler arrangement of claim 6, wherein the index of refraction of material forming said prism and the angle of bend formed between respective central longitudinal axes of said inlet and outlet arms are chosen so that said substantially all light

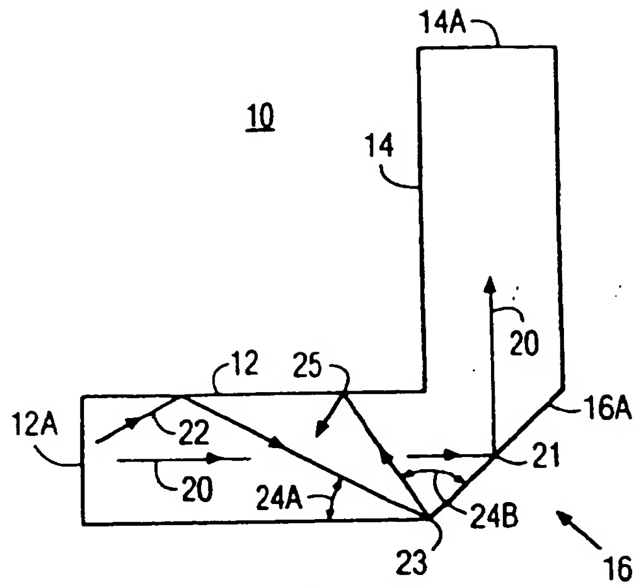

FIG. 1
PRIOR ART

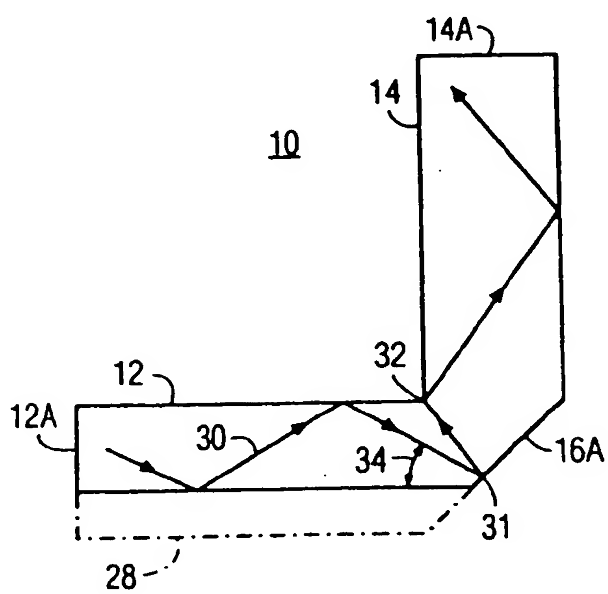

FIG. 2

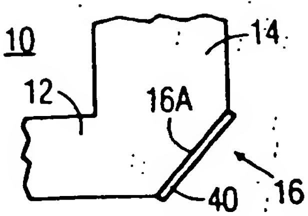

FIG. 3

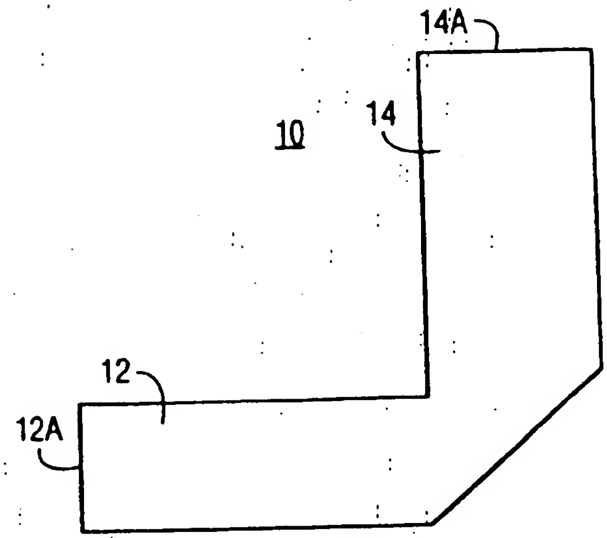

FIG. 4

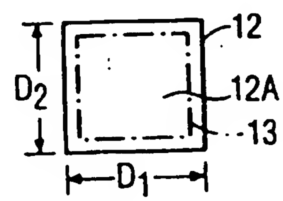

FIG. 4A

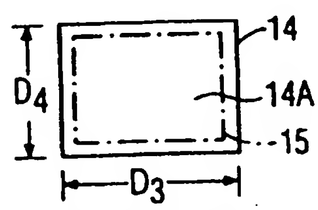

FIG. 4B

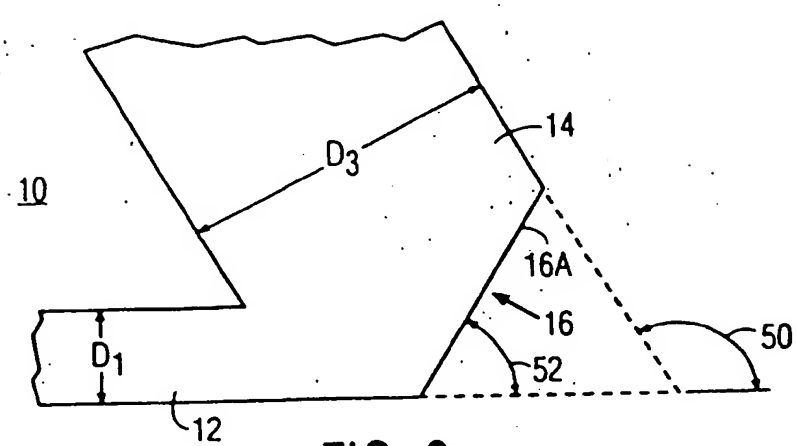

FIG. 6

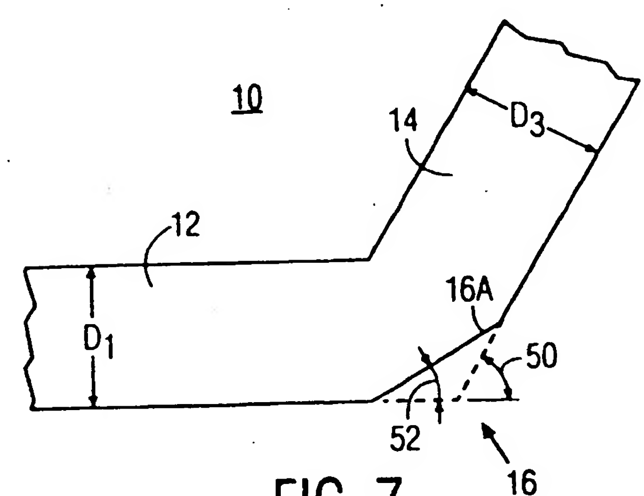

FIG. 7

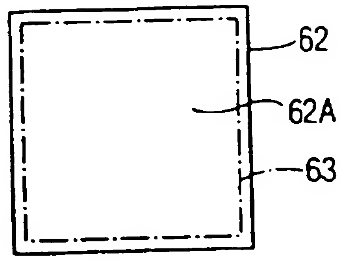

FIG. 8A
PRIOR ART

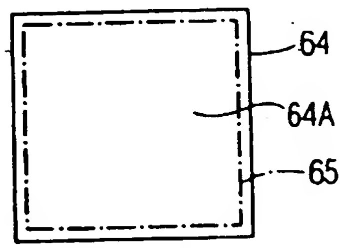

FIG. 8B
PRIOR ART

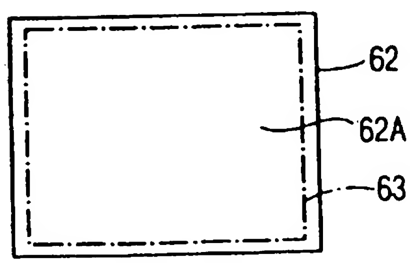

FIG. 9A

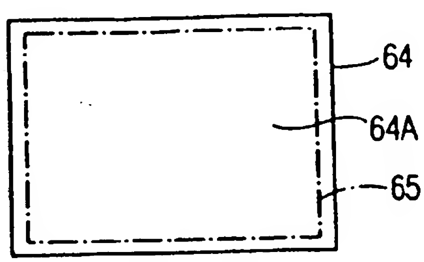

FIG. 9B

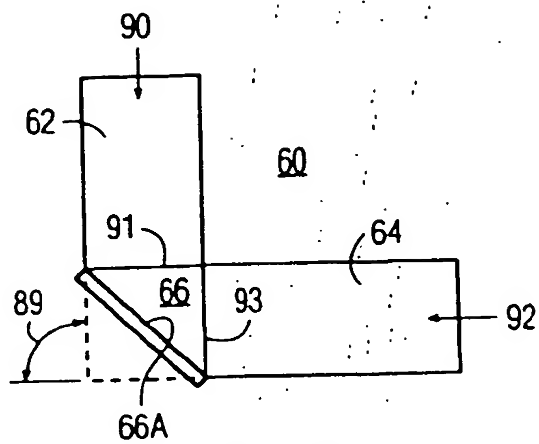

FIG. 13

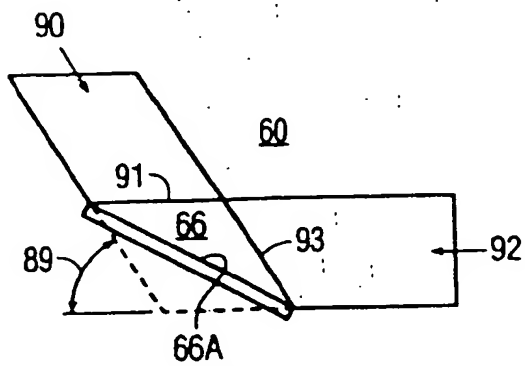

FIG. 14

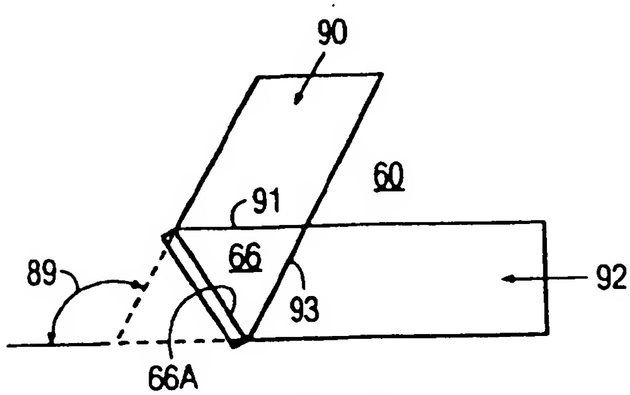

FIG. 15

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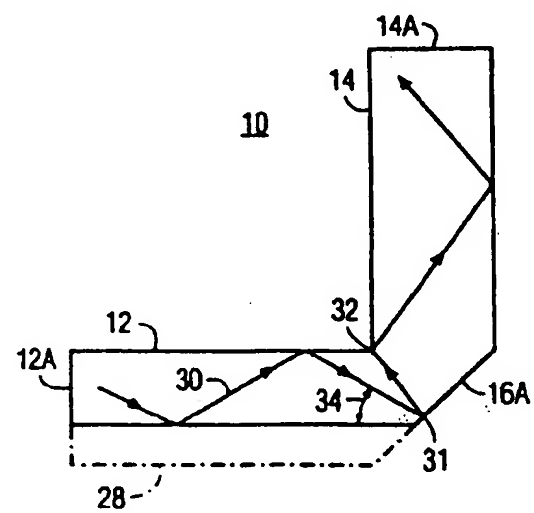

FIG. 2

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EUROPEAN SEARCH REPORT

Application Number
EP 96 30 6878

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	29 July 1999	Mathyssek, K

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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EUROPEAN SEARCH REPORT

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
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